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Impact of Gravel Extraction on Stream Morphology and Biotic Communities in Streams of Vanua Levu Fiji.

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Abstract— Gravel extraction refers to the actual process of removal of gravel from a place of occurrence. The increase in demand for gravel for construction purposes has placed immense pressure on the environment where these resources occur. Gravel extractors employ different methods of extraction along river channels and their flood plains. Using environmental impact assessment guidelines, a host of environmental aspects were identified along Labasa, Dreketi (Naua) and Tabia Rivers of Vanua Levu. These aspects include collapsing river banks, habitat destruction, and impact on water quality, flora, fauna and riparian vegetation. These aspects have a significant impact on environmental functionality of the valley. It is therefore, concluded that there is need for more environmental regulations and stringent monitoring system to be developed and implemented.

Keywords - ***River morphology, Impacts, Gravel extraction, Environment.***

I. Introduction

Fiji Islands is blessed with number of rivers and creeks which have abundant quality rocks, gravels and sand and rich biodiversity of flora and fauna. These rivers contain many indigenous fish species, crustaceans, gastropods and insect species [1]. Fiji's rivers and streams are a little recognised resource in traditional Fijian way of life because of limited knowledge of biodiversity and functionality of aquatic ecosystem. The greatest perceived value is a source of gravel and rocks for the construction industry and consequent "gravel rental" or lease rights for adjacent landowners. The increasing and unsustainable manner in which gravel and boulders are being extracted is causing major ecological changes in many of Fiji's rivers and streams, and major hydraulic changes, the economic impacts of which are beginning to be felt in the form of increased and more extreme flooding, loss of fertile land, increasing sedimentation at downstream and the undermining of the foundations of bridges and Irish crossings. The economic costs to the nation of increased severe flooding increased dredging and the replacement of riverine infrastructure will be enormous, and will be paid for by taxpayers, and not the extractors of gravel and boulders.

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Until very recently, it was believed that Fiji's freshwater biodiversity was limited and uninteresting with no, or minimal, endemism. However, in the last five years research has shown that this assumption is very wrong. Around 143 species are known that spend at least half of their lives in freshwater. Of these about 122 are spending the bulk of their adult lives in freshwater (the other 21 species are spending the bulk of their sub-adult lives in freshwater). 132 of these are native species and 11 species are known well established populations of introduced fishes. There are at least 10 endemic species of Fijian fishes that inhabit freshwater systems for much of their lives. There are at least five species that could be considered endangered [2].

The extraction of river gravel or sand and associated redistribution of sediment and ecological disturbance resulting from such activities in river is generally considered injurious to the overall aquatic habitat [3], [4]. Fiji's rivers, in their natural state, are a mixture of quiet pools or riffles of slow moving water, interspersed with whitewater rapids of variable length and water velocity. This is the natural order of rivers and Fiji's native biodiversity are adapted to this alternating river passage and habitats. Excessive extraction of river material eliminates habitat differentiation (pools and riffles) and the river takes on the characteristics of a smooth, culvert with a lowered river base course. The changes in river morphology due extraction activities affect the biotic communities of river ecosystem.

The purpose of this paper is to identify and assess the environmental impacts of gravel extraction along Labasa, Naua and Tabia Rivers. Therefore, following this introduction is an outline of the research methods and the results and discussion. The paper closes with some concluding remarks.

II. Methodology and Material

A. Description of study sites

The study was conducted on three rivers of Vanua Levu from which intensive gravel extraction has taken place. The extraction is basically for the purpose of upgrading of roads in Vanua Levu. Naua River is a tributary of Dreketi River and located at Naua, the Dreketi district of Macuata Province which is 55 km west of Labasa Town. The extraction site is 100m upstream of Naua Bridge which is non tidal river. The coordinates of the study site are; Latitude is 16^0 37’ 02.45” South, Longitude is $179^0$00’01.05” East and Elevation is 15.3 m. The study site is surrounded by secondary vegetation of pine trees (*Pinus caribaea),* raintree (*Samanea saman),* coconut plantation (*cocos nucifera*) and scattered shrubs and grassland.

Labasa River study site is located at 10km south west of Labasa town at Korotari, the Wairiki District of Cakaudrove Province. The coordinates of the study site are; Latitude is 16^0 31’ 09.05” South, Longitude is $179^0$23’ 28.98” East and Elevation is 13 m. The river flows from Delaikoro Mountain through sugar cane farming catchment and beside Labasa town into the Great Sea Reef. The area of the study site was 1km which consists of riffle and pool habitats and adjacent land to the stream consist of sugar cane farming and vegetables. The stream bed had cobbles, gravel and silt deposition and stream depth was 15 to 25cm and average width was 25cm.

Tabia River study site is located at Tabia in Sasa district of Macuata Province, which is 12 km west of Labasa Town. The coordinates of the study site are; Latitude is 16^0 27’ 43.88” South, Longitude is 179^0 14’ 49.06” East and Elevation is 14 m. This small narrow stream with low water velocity and surrounded by sugar cane plantation and vegetable farming. The stream consists of riffle, pool and run with average depth of 15cm to 25 and average width of 15m. The stream bed has high deposit of following substrate types: silt, gravel and small cobbles.

B. Assessment and Data Collection

At each sites environmental impacts were identified and analyzed for bank stability and erosion, river channel morphology, riparian vegetation, water quality parameters and macroinvertebrates abundance. Assessment was conducted before and after the extraction activities. For water quality parameters, measurements were taken in situ before and after extraction activities.

Macroinvertebrates samples were collected from three different habitats within each site (pool, riffle and run habitats). Samples were taken using a triangular-frame kick net (0.5mm mesh size). At each site kick net was placed in the water with open end facing into the water current. The riverbed immediately upriver of the net is then disturbed using samplers feet and hands to the water depth of 15cmm for 2 minutes so that dislodged materials is carried into the net. The kick net contents were then emptied into a collecting tray once net became heavy or half full. Once all samples were emptied into the tray, large plant matters, cobbles or stones were washed and removed from the sample in order to minimize the overall volume. These samples were then preserved in 85% ethanol and stored in plastic screw top, 100 ml containers. Sample labels (sample number, date, time and collector’s name) were placed both in and on the sample containers. The samples were then returned to the laboratory for sorting and identification of the macroinvertebrate taxa.

FIGURE 1. STUDY SITES ON THREE RIVERS

III. RESULTS

The table below provides the assessment of environmental impacts at each site after the extraction activities.

TABLE 1. RESULTS OF IMPACT ASSESSMENT

Parameters	**Environme-ntal**	**Impacts**	
	Labasa	**Tabia**	**Naua**
Riparian Vegetation	Part of riparian vegetation removed for access road	Part of riparian vegetation removed for access road	Part of riparian vegetation removed for access road
River bank	Bank damaged and eroded	Bank damaged and eroded	Bank damaged and eroded
River Channel	Multiple pools due to instream digging	Stockpiled in mid stream and multiple pools	Stockpiled in mid stream and multiple pools
Stream Bed	Unstable, slow flow of water and no riffle habitat	Unstable, slow flow of water and no riffle habitat	Unstable, slow flow of water and no riffle habitat

All the study sites have significant negative impact to the environment due to irresponsible way of extracting gravel by the contractors. The damage to river bank and removal of vegetation, stream bed stability will cause more damage to adjacent environment and downstream during heavy rainfall.

TABLE 2. WATER QUALITY PARAMETERS

	Labasa		Tabia		Naua	
Parameters	**B**[1]	**A**[2]	**B**	**A**	**B**	**A**
Temperature 0^C	27	27	28	29	28	28
pH	7.1	6.8	7.3	6.5	7.2	6.7
Conductivity µS/cm	100	150	120	200	110	160
Turbidity NTU	6	8	7	10	9	10
D O mg/l	12	7	13	8	7	8

There is not significant change in water quality parameters before and after extraction activities. The results for after extraction were recorded after a week of extraction.

TABLE 3. MACROINVERTEBRATE SAMPLING

			Labasa		Tabia		Naua	
Order	**Class**	**Family**	**B**	**A**	**B**	**A**	**B**	**A**
Arthropoda	Insecta	Odonata	80	0	50	0	10	0
		Ephemeroptera	120	0	55	0	5	0
		Diptera	45	0	4	0	3	0
		Trichoptera	130	0	65	0	5	0
Annelida	Hirudinea	Oligochaeta	0	0	0	0	0	0
Mollusca	gastropod	Caenogastropoda	10	3	4	4	3	2
Arthropoda	Crustacea	Decapoda	4	10	10	9	2	1

Overall, the class insect was most abundant macroinvertebrates taxon recorded with 4 families. Insecta families Ephemeroptera (mayfly), Trichoptera (caddis fly) were the most abundant taxa recorded, followed by the insect orders Diptera and Odonata in samples before extraction activities. All insect groups were absent in all three site after extraction activities. The only macroinvertebrate that were present after extraction sites were gastropoda (Caenogastropoda) and crustacean (decapoda).

IV. DISCUSSION

A. Stream Morphology

Gravel mining can continue to remove large amounts from a single location on a stream because periodic spates deliver fresh deposits from upstream. When the entrained gravel reaches the enlarged channel at the mined reach, the water slows and the gravel is deposited. Excessive movement of gravel down slope to fill the hole in the streambed results in channel erosion upstream (i.e., head cutting [5]. Stream-banks are eroded laterally more than vertically because bedrock underlies most gravel streambeds. Lateral erosion results in the undercutting of riparian trees, which then fall into the stream channels but not necessarily into the water. The widening of the stream channels results in the loss of stream competence (ability to transport bed load) because flow is slower in the larger channels. Loss of competency delays reestablishment of concordance between channel shape and stream flow patterns.

The removal or disturbance of in-stream roughness elements (large stones and boulders, tree trunks, branches, woody debris) during gravel extraction has a negative effect on the amount and quality of aquatic habitat [6]. Fish need calm water and hiding places in order to survive. If these places are removed from a river, along with the river armoring, they are very difficult to reestablish because of increased erosion and stream channel movement.

B. Biotic Communities

Biotic communities that we measured (invertebrates) were affected by gravel extraction. Significant decreases in macroinvertebrates were observed that are sensitive to stream habitat alteration such as insect group, ephemeroptera, tricoptera and odonata [7], [8]. Alteration of normal riffle–pool morphology, flow patterns, and fine-sediment transport apparently resulted in the observed responses by the streams' communities. Distribution of biota in gravel bed streams is strongly related to physical habitat, which is dominated by riffle–pool structure [9], [10], [11]. Some animals that live primarily on riffles (e.g., filter-feeding invertebrates) depend on food resources produced in pools [10]. Other organisms, such as drift-feeding fish, often reside in pools and exploit invertebrates produced in riffles. Changes in ratios among riffles, pools, and flats should be expected to alter the community structure and ecological functioning of gravel bed streams.

Environmental degradation extended far beyond the boundaries of the immediate gravel extraction areas. Head cutting has major consequences for many kilometers upstream from the extraction site [12], [5]. Downstream areas had too little gravel bedload to maintain normal stream channel structure because gravel was intercepted at the mines. Silt travels long distances downstream as a plume of turbidity while gravel is being removed. During floods, turbidity is likely to be higher than normal for even longer distances downstream due to the higher flow rate and increased entrainment of sediments as a result of channel deformation.

There appears to be no way to successfully avoid or mitigate the effects of gravel removal on stream ecosystems as long as gravel is removed from within the bank-full confines of the stream channels. Physical structure is the very foundation upon which stream communities are assembled, and this appears to be especially true for gravel bed streams because of their predictable shape. Fundamental changes in water quality and the total biotic community are to be expected when the physical structure of streams is altered. Recovery time appears to be measured in decades [13]. Total restoration of severely affected streams would probably be impossible.

The large riparian trees that have been undercut as a result of channel widening induced by head cutting and erosion cannot be replaced, at least in their natural positions, because the soil in which they were rooted is no longer in place. Gravel mining from stream channels seems to create an irreconcilable multiple-use conflict among the various users of gravel bed stream resources.

[1] Before Extraction
[2] After Extraction

V. CONCLUSION

The world's freshwater ecosystems are under threat from an increasing global population, associated socio-economic pressures and, particularly in developing countries, where natural resources are used unsustainably for development activities. Such pressures are clearly evident within Fiji, where particularly, river gravel is extracted for development use. Protecting natural waterways is unquestionably a key environmental priority for Pacific Island countries such as Fiji, as aquatic ecosystem is a critical natural resource necessary for sustainable human and economic development.

Increased River gravel Extraction without proper guideline or policy is destroying aquatic ecosystem and associated physical infrastructures in Fiji. The country need to develop gravel extraction policy and comprehensive monitoring programme.

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